Title	Kyutech's Model for Space Engineering Capacity Building in Emerging Countries
Author(s)	Polansky, John L.; Cho, Mengu
Issue Date	2016-03-31
URL	http://hdl.handle.net/10228/5607
Rights	

Kyutech's Model for Space Engineering Capacity Building in Emerging Countries

(Received November 30, 2015)

John L. POLANSKY and Mengu CHO

Laboratory of Spacecraft Environment Interaction Engineering

Kyushu Institute of Technology

Abstract

Nowadays, small satellite and lean satellite projects proliferate worldwide. Many countries, especially emerging countries, try to enter the space sector through development, launch and operation of small satellites. For those countries to initiate sustainable space programs, however, there are barriers such as lack of funding and infrastructure and underdeveloped human resource. They seek collaboration with institutions in space faring nations to build indigenous space capability. Since 2009, Kyushu Institute of Technology (Kyutech) has been engaged in space-related capacity building and international cooperation in the area of small/lean satellites. In 2011, Kyutech launched a long-term fellowship program partnering with the United Nations Office for Outer Space Affairs (UNOOSA). Based on the success of the first two years, Kyutech expanded the program significantly in 2013, launching a new post-graduate program, Space Engineering International Course. This paper provides an overview of the university-based model adopted by Kyutech to promote the capacity building and human resource development in emerging countries. The paper compares various approaches toward the capacity building.

Keywords: Capacity Building; Human Resource Development; Space Engineering Education; Lean Satellites; Small Satellites; Emerging Countries

1 Introduction

The barrier to space access is falling. Despite issues such as lack of funding, apathetic political support, limited technology, lack of expertise, and underdeveloped human resources, over 30 new countries are projected to achieve space access this decade [1]. Small satellites are lowering this barrier to space for emerging countries. The number of small satellites launched annually has increased by an order of magnitude since 2011, and the global market for satellites less than 50kg is projected to grow from ~$700M USD in 2014 to ~$2B USD by 2019 [2]. Many of these satellites can be categorized as "lean satellites" that employ untraditional risk-taking development approaches to achieve low-cost and fast-delivery with small teams. Utilizing the advantages of lean satellites, emerging countries and institutions can now much more quickly cycle through design, development, launch, and operation [1].

There are various models designed to provide support for small and lean satellite activities, such as programs conducted by established space agencies, purchases from private companies, commercial training packages, university-based practical education, etc. Numerous direct and tangential benefits can be leveraged in the process. Space faring nations and established space institutions have both for-profit and non-profit incentive to contribute to basic space technology and human resource development in emerging countries. However, emerging countries are not equipped to reap the benefits of space access by simply launching or operating a small or lean satellite. These launches are crucial but not sufficient first steps to initiate value-added space programs. The personnel and workforce must be adequately equipped to propagate sustainable space activities within their home countries.

This paper concerns Kyushu Institute of Technology's university-based model to enhance space-related capacity building and human resource development in emerging countries worldwide, and discusses advantages and disadvantages of alternative approaches. A related publication [1] by the authors that has been submitted for review gives an overview of space-related activities in various emerging countries and categorizes countries in nine regions worldwide according to level of satellite activity. In Sec. 2 we provide the project background; in Sec. 3 we describe our university-based model for capacity building; in Sec. 4 we discuss implications of lean satellites; Sec. 5 is discussion on capacity building intent and alternative approaches and Sec. 6 is the conclusion.

2 Project background

2.1 Kyushu Institute of Technology

Kyushu Institute of Technology (Kyutech) is a Japanese national university founded in 1909. Kyutech is located in the city of Kitakyushu, which has a population of over 1 million people and is known as the birthplace of Japanese modern industry. Since 1993, Kyutech has provided space engineering education in Japanese to undergraduate and graduate students under the Department of Mechanical and Control Engineering. In 2004 Kyutech established a new research center, the Laboratory of Spacecraft Environmental Interaction Engineering (LaSEINE), to study and develop technology to overcome engineering challenges in the space environment. In 2010 a new research division, the Center for Nanosatellite Testing (CeNT) was added to LaSEINE. With the exception of radiation testing, CeNT provides all environmental tests necessary for the development of small satellites and satellite components with size and weight up to 50cmx50cmx50cm and 50kg, respectively. CeNT is staffed by Kyutech professors, researchers, and professionals who have extensive practical and theoretical testing experience, and since its inauguration CeNT has provided or is providing environmental tests to over 20 Japanese and international satellites.

Since 2011 Kyutech and United Nations Office for Outer Space Affairs (UNOOSA) have been offering long-term fellowships on nanosatellite technologies to foreign post-graduate students. In 2013 the fellowship programme expanded, and Kyutech established an English-based degree curriculum, the Space Engineering International Course (SEIC), open to fellowship and non-fellowship Masters and Doctoral students. Additionally, Kyutech and LaSEINE have been developing the HORYU nanosatellite series since 2006, successfully launched and operated HORYU-II in 2012 [3, 4], and anticipate launching HORYU-IV in 2016.

The combination of these activities has positioned Kyutech for space-related collaboration with foreign institutions worldwide.

2.2 Project overview

The primary objective of Kyutech's space-related capacity building project is to educate and train engineers and students from countries with limited space/satellite capacity such that participating individuals are capable of returning the skills and knowledge gained to their home countries or institutions.

Kyutech's space-related capacity building project took hold in 2013 upon receipt of funding from the Japanese government for 30 post-graduate fellowships dedicated to students from non-space faring nations[1]. This joint United Nations/Japan fellowship programme is named Post-graduate study on Nano-Satellite Technologies (PNST). PNST allows Kyutech to award six fellowships per year for five years (2013 to 2017) to nationals of developing countries or non-space faring nations. PNST students relocate to Kyutech and enroll in SEIC to study space engineering and satellite technology.

Recruiting an equal number of self-funded[2] students alongside the PNST fellows was established as a parallel priority. Optimal PNST and self-funded candidates typically fall into one of the following three categories:

1. Engineers who belong to space agencies or space-related companies
2. University students likely to return to home country to start/lead satellite programs
3. Individuals from institutions interested in joint research or training opportunities

Optimal candidates are also highly motivated leaders, academically strong, and committed to utilizing newfound expertise in their home country or region. Kyutech does not mandate PNST or self-funded students to return home to work or research following completion of their degrees[3], although it is strongly encouraged. Kyutech understands that no relevant or desirable opportunity may exist locally for students.

[1] According to fellowship requirements "countries without an established substantial capability to develop space technology/launch space objects"

[2] Financially supported by home country, home institution, or other non-Kyutech means

[3] Sending institution or funding institution may impose such requirements

Accordingly, a major component of Kyutech's capacity building project is to initiate and establish sustainable partnerships with space-related institutions worldwide that are committed to active space-related projects and initiatives.

Traveling to local institutions simultaneously allows seminars with prospective students, direct assessment of facilities and infrastructure, and enhanced professional relationships. This approach has been employed in Africa, the Middle East, Central/ North America, South America, Eastern Asia, Southern Asia, Southeast Asia, and Oceania in the prior two years.

To summarize, the goals of the project are to recruit students, assess local conditions first-hand, establish partnerships, and continually lower the barrier to space.

2.3 Motivation

Emerging countries worldwide can benefit technologically, economically, and socially from domestic space-related activities [5–7]. However, limited resources and lack of know-how prevent many non-space faring nations from initiating space projects, much less building sustainable space or satellite programs [8]. By focusing on human resource development through hands-on satellite projects Kyutech is able to directly address an inhibit common to nearly all early-stage satellite projects in target countries. Kyutech is a relatively young in this field. Numerous entities exist as mentors to emerging space nations. For example:

- APRSAF (Asia-Pacific Regional Space Agency Forum)
- APSCO (Asia-Pacific Space Cooperation Organization)
- EAPSI (East Asia and Pacific Summer Institutes)
- IAF (International Astronautical Federation)
- ISU (International Space University)
- SGAC (Space Generation Advisory Council)
- UNISEC (University Space Engineering Consortiums)
- UNOOSA (United Nations Office for Outer Space Affairs)
- Established space countries such as China, France, Japan, USA, etc.

- Private companies such as Lockheed Martin and many others
- Space agencies such as NASA, ESA, JAXA, etc.
- Universities such as University of Surrey and California Polytechnic State University

All involved institutions have either for-profit or non-profit incentive (or both) to contribute to basic space technology and human resource development in emerging markets. Kyutech seeks to add value to the global community effort through its own university-based training model. The Kyutech model is described in Sec. 3. Kyutech is a non-profit educational institution. However, it must be stated that multiple aspects of Kyutech's space-related capacity building project are directly supported by the Japanese government.

The domestic satellite market in Japan is limited, and Japan has incentive to sell satellites to other countries as infrastructure exports. In doing so training of local engineers is crucial. This training can be accomplished by JAXA, private companies, domestic universities, or a combination thereof. For example, in 2011 Mitsubishi Electric Corporation signed a contract with Turkey for two communications satellites and training of Turkish engineers was performed at Mitsubishi facilities in Japan [9, 10]. In another case in 2011, NEC Corporation was awarded two remote sensing satellite orders from Vietnam [11], with the first satellite to be built in Japan, and the second in Vietnam, with training of Vietnamese engineers to be conducted at multiple Japanese universities (including Kyutech).

Kyutech's capacity building program is also constructive to Japanese diplomacy, as outlined earlier this year in Japan's new 10-year space development policy the "Basic Plan on Space Policy."

2.4 Objectives

Objectives of Kyutech's space-related capacity building project are considered in the context of participating individuals, participating institutions/countries, UNOOSA, Kyutech, and Japan. Objectives for each of the five stakeholder categories are listed below:

1. Participating individuals
    (a) Earn graduate degree
    (b) Advance career and earning potential
    (c) Acquire skills necessary to initiate and lead satellite project
    (d) Access top-notch research laboratories and satellite development/ testing centers
2. Participating institutions/countries
    (a) Staff training
    (b) Human resource development
    (c) Joint space-related research opportunities
    (d) Satellite testing services and launch opportunities
3. UNOOSA (from [12])
    (a) Respond to the growing interest in many countries to establish indigenous capacities in basic space technology
    (b) Address the increasing role of small (nano-) satellites for education, basic space science and for operational application
    (c) Assist countries to ensure adherence to the relevant regulatory frameworks and promote the use of standards
    (d) Promote international cooperation and information exchange in capacity building in basic space technology
4. Kyutech
    (a) Increase horizontal breadth and vertical depth in space research
    (b) Increase research and student funding
    (c) Improve academic recognition and reputation internationally and domestically
    (d) More robust in-house satellite projects
    (e) Broader national and international collaboration

5. Japan
    (a) Enhance space-related economic viability
    (b) Achieve strategic objectives
    (c) Strengthen diplomatic ties

2.5 Expected significance

The direct significance would be for all five major stakeholders to accomplish the objectives listed in Sec. 2.4. Progress made thus far is quantified in Sec. 3. Tangential significance includes improving the overall reliability of small and lean satellites missions, proliferation of successful lean satellite projects, and intercultural benefits.

In 2013 and 2014 combined over 200 CubeSats were placed into orbit, yet over 45% are presently inoperable (note: includes CubeSats that have reentered the atmosphere) [13]. The community estimates the in-orbit success rate of university-led CubeSats to be around 50%. Kyutech aims to equip students and trainees with the capability to improve in-orbit success rates of future satellite missions. Proliferation of increasingly successfully small and lean satellite projects may in turn lead to de-facto space qualification of numerous commercial-off-the-shelf (COTS) parts and components, in turn accelerating future, more successful projects. Kyutech's capacity building project also seeks to develop global engineers possessing profound intercultural communication and systems engineering prowess. This applies to both Japanese and foreign participants. At present less than 1% of Kyutech undergraduate students are foreign, and only ~10% of graduate students. This project is increasing the number of foreign graduate students and requires substantial teamwork between various cultural groups. Economic benefits may stem from global competency of the workforce.

3 Kyutech's university-based model for space-related capacity building

Many dozens of universities are now utilizing satellite projects as official educational tools. Some universities have been doing so for decades, such as the University of

Surrey and the University of Tokyo. Kyutech's model seeks to influence space-related capacity building worldwide through requirements inherent to all satellite projects: space environment testing and launch opportunities.

Kyutech's model emphasizes laboratory research for practical space engineering applications, space environment testing on small[4)] satellites, and hands-on responsibilities in satellite projects having bona fide launch opportunities. Students and engineers engage in these three activities throughout their multi-year graduate degrees. In doing so participants come to understand the infrastructure necessary for various levels of satellite activity.

Under this model Kyutech is engaging countries worldwide in a five-pronged approach to develop satellite capability and accomplish the objectives listed in Sec. 2.4. The approach consists of the following five elements:

1. Assessment of local conditions, infrastructure, and resources
2. Education and human resource development
3. Official agreements to spur collaboration
4. Low-cost and fast-delivery satellite testing
5. Assistance with launch opportunities

To achieve 1, the authors spend ~4 months on travel in ~20 countries per year. The trips consist of student recruitment, initiating partnerships and collaboration, and negotiating over personnel training and education, satellite testing, joint launch opportunities, and joint research.

To achieve 2, Kyutech utilizes its English-based SEIC graduate degree curriculum that was launched in April 2013. The all-inclusive annual cost for a student to attend Kyutech is ~$20-25K USD. Six foreign students per year from non-space faring countries are fully supported by the United Nations/Japan long-term PNST fellowship programme. SEIC is also open to non-fellowship students from any country and any

---

[4)] For testing equipment purposes limited to 50cm in a given dimension and 50 kg in weight relevant background. A critical component of Kyutech's model is to create mutually beneficial partnerships in which foreign institutions partially or fully fund candidates for SEIC.

To achieve 3, Kyutech works with partner institutions to sign Memorandums of Understanding (MOUs) pertaining to student/staff exchange and joint research, Double-Degree Program (DDP) agreements for joint long-term educational efforts, contracts for satellite testing, contracts related to launch opportunities with JAXA, or other official agreements. The objective is to create sustainable relationships and a Kyutech global network that does not over rely on external funding.

To achieve 4, Kyutech employs low-cost and fast-delivery satellite testing that is not possible for large-scale satellites but is possible for the growing class of small/lean satellites. This testing has been instrumental to the development of the standard ISO-19683/CD on small/lean satellite environment testing. The ISO standard is not yet published[5] but in the meantime Kyutech follows the standard and encourages partners to do so as well. Multiple students and researchers in Kyutech's laboratories are continually working to improve the standard and testing process. Domestic and international institutions are able to test small/lean satellites or train staff members in CeNT, for a fee.

To achieve 5. Kyutech works with the JAXA Kibo Utilization Office for Asia to enable foreign institutions to launch nanosatellites from the ISS (International Space Station). JAXA requires that a given foreign institution have a Japanese partner to be eligible for extremely competitive launch costs.

3.1 Kyutech global network

The five principal tasks listed above have been pursued worldwide by Kyutech since 2013. Kyutech's global network for space-related capacity building extends to over 40 countries across six continents as of this writing. Collaboration status worldwide is totaled in Table 1.

---

[5] Projected to be published in 2016

Table 1: Kyutech worldwide collaboration status totals as of this writing

Local visits:	43
Agreements in progress:	10
Agreements official:	14
PNST students	21
Self-funded students:	26

Table 2 gives the total number of Kyutech official agreements, pending agreements, local visits, PNST students, and self-funded students by region[6]. At present Africa and Southeast Asia are Kyutech's strongest regions. Central/North America and South America are up-and-coming regions of Kyutech collaboration. Table 2 includes 2015 PNST and self-funded students who are relatively certain to matriculate in October 2015.

Table 2: Kyutech collaboration status by region

	AF	ME	CN	SA	EA	SN	SE	EE	OA	**Total**
Local visits:	8	1	5	11	1	1	15	0	1	43
Agreements in progress:	3	0	2	2	1	0	1	0	1	10
Agreements official:	2	1	1	0	1	1	8	0	0	14
PNST students:	6	1	2	1	3	1	4	3	0	21
Self-funded students:	9	1	2	1	1	2	9	0	0	26

3.2 Importance of university speciality area

For a university to maintain a global capacity building network it is important to have a speciality area with broad appeal. Kyutech's speciality with respect to small/lean satellites is space environment testing. By definition satellites reaching orbit are subject to the space environment. Therefore a minimum requirement for any satellite project is space environment engineering or testing. Testing yields diminishing returns in defect detection rate and cumulative defects detected as a function of longer testing time [14]. In other words, the highest value testing occurs in the first testing segment. With properly targeted test selection even teams with extremely

[6] AF: Africa, ME: Middle East, CN: Central/North America, SA: South America, EA: Eastern Asia, SN: Southern Asia, SE: Southeast Asia, EE: Eastern Europe, OA: Oceania

limited resources can markedly improve reliability and protect against infant mortality.

At Kyutech satellite testing is conducted in the Center for Nanosatellite Testing (CeNT). CeNT is capable of testing satellites and satellite components with size and weight up to 50cmx50cmx50cm and 50kg, respectively. Tests include vibration, shock, thermal vacuum, thermal cycling, electromagnetic compatibility, outgassing, and others. CeNT is leading small satellite testing in Japan. Approximately two-thirds of all Japanese small satellites and many foreign small satellites conduct environmental testing at CeNT. CeNT strives to provide low-cost fast-delivery satellite testing. This approach is beneficial to both individual satellite projects and the community as a whole.

In general, a given university or academic center running a broad-scale capacity building network should have at least one speciality or focus area to attract a wide range of users and to compensate for possible lack of resources compared to government agencies, private companies, etc. If no such speciality area exists, entities may turn to "resource providers" that specialize in university projects, such as those found in [15] for satellite activities.

3.3 Importance of national policy and international cooperation

The Government of Japan supports various elements of Kyutech's capacity building project, including PNST fellowships through Monbukagakusho (MEXT), ISO standardization activities through the Ministry of Economy, Trade and Industry (METI), and the HORYU-IV nanosatellite project through the Japan Society for the Promotion of Science (JSPS). Also, UNOOSA supports and advocates internationally on behalf of the PNST fellowship programme.

3.4 United Nations/Japan long-term fellowship programme

To enable foreign students from non-space faring countries to participate in nanosatellite-based capacity building, UNOOSA and the Government of Japan in conjunction with Kyutech established a fellowship programme named Doctor on

Nano-Satellite Technologies (DNST) in 2011 to support two Doctorate students per year. In 2013 the fellowship program expanded to support up to six students per year (two Masters students and four Doctorate students) and was renamed Post-graduate study on Nano-Satellite Technologies (PNST). In 2013 there were 83 applications from 28 countries. In 2014 there were 120 applications from 55 countries. In 2015 there were 45 applications from 22 countries. PNST will continue awarding six fellowships per year through at least 2017.

The joint UNOOSA-Japan objective is to establish indigenous capacity in basic space technology in non-space faring nations as the fellowship students return home. Full details can be found in [16–18]. Kyutech encourages foreign countries and institutions to send and support additional candidates in order to accelerate capacity building.

3.5 Space Engineering International Course (SEIC)

Kyutech's Space Engineering International Course (SEIC) curriculum was launched in April 2013. SEIC is English based and requires two years for a Masters degree and three years for a Doctorate degree. SEIC is open to any student, Japanese or non-Japanese, who registers as a full-time graduate student at the Graduate School of Engineering. SEIC consists of the following four components:

1. Research toward a Master or Doctoral degree
2. On-the-job training in space environment testing
3. Project-based learning through a space project
4. Lectures in English on space engineering

Students participating in Kyutech's global capacity building project join SEIC. As of October 2014[7)] there were 16 Japanese and 19 foreign students enrolled in SEIC. Countries represented were Algeria, Colombia, Egypt, France, Ghana, Indonesia,

[7)] Foreign students typically matriculate in Octorber

Mongolia, Nigeria (x2), Philippines, Romania, Singapore, Sudan, Ukraine (x2), and Vietnam (x4). Additional details on SEIC can be found in [17, 18].

3.6 Management team

Kyutech's global space-related capacity building project is managed primarily by two members of LaSEINE, with support from the Faculty of Engineering and International Affairs Division. The PNST fellowship programme is managed by two members of LaSEINE and one person from UNOOSA. SEIC is managed by numerous professors across Kyutech's engineering departments, with support from the university administration, Faculty of Engineering, and Dean of Engineering.

4 Importance of Lean Satellite definition

It is well-accepted that a GEO satellite is "large" and a CubeSat is "small". However, for the growing class of satellites in between, and for CubeSats or other satellites that are adopting untraditional design approaches, a sized-based term such as "small" is ambiguous with respect to describing the category. In fact, for this growing category, design philosophy is rapidly changing. The category is characterized by small/micro/nano/pico satellites utilizing unconventional processes to achieve low cost and fast delivery. "Large" satellites are not necessarily excluded from adopting a similar approach, but typically are unable to do so by virtue of their relatively high cost and heightened requirements. However, for these new unconventional satellites, reliability is a major issue. In some cases reduced reliability is inherent to the design, while in other cases reliability could be substantially improved with better engineering and adequate testing.

For educational, research and development, or scientific satellites that are unconventional, failure rates as high as 50% may be tolerable, if not satisfying. Yet, as this category of satellites is commercialized or used to initiate space programs, such failure is no longer acceptable. Low success rates jeopardize funding and generate significant negative publicity. Numerous benefits will follow from defining the type of satellite that comprises this category and by establishing applicable testing standards.

For example, facilitation of international trade, performance verification on the ground, streamlined international collaboration, and improved reliability. The goal is to move from a high likelihood of infant mortality to a low likelihood of random failure [14]. Defining requirements of satellites within this category will also be beneficial to space debris and frequency allocation concerns.

A proposed term that captures the design philosophy is "lean satellite". A formal definition of lean satellite is under development. The authors are secretary and co-chair, respectively, of International Academy of Astronautics (IAA) Study Group 4.18 "Definition and Requirements of Small Satellites Seeking Low-Cost and Fast-Delivery". The Study Group has determined that the name "lean satellite" captures the general idea of employing untraditional risk-taking satellite development approaches to achieve low-cost and fast-delivery with small teams. In October 2015 the Study Group will produce a preliminary draft report[8)] containing an explanation of lean, lean satellite classification methodology, and lean satellite requirements.

The Study Group definition and classification methodology will also clarify possible confusion related to the term "lean satellite" used in ISO-19683/CD "Space systems - Design Qualification and Acceptance Tests of Lean Satellites and Units". ISO-19683/CD seeks to provide test methods and test requirements for design qualification and/or acceptance of lean satellites or units seeking low-cost and fast-delivery in an effort to improve lean satellite reliability to an acceptance level suitable for commercial investment. Please note that use of the term "Lean Satellites" in ISO-19683/CD is subject to change. ISO-19683/CD is projected to be published in 2016.

4.1 Lean satellites as capacity building tools

As shown in Fig. 1, there has been explosive growth of small satellites launched since 201210. This trend presents new opportunities for emerging countries to access space. Many of these small satellites are also lean satellites, offering short development

---

[8)] Open discussion on the preliminary draft to be held during 66th IAC in Jerusalem October 12-16 2015 times (order of many months to a few years), agile design and testing, and low-cost launch opportunities with respect to traditional satellites. However, infant mortality of small/lean satellites remains high (some estimates around 50% for university-led projects), jeopardizing commercial use and capacity building activities.

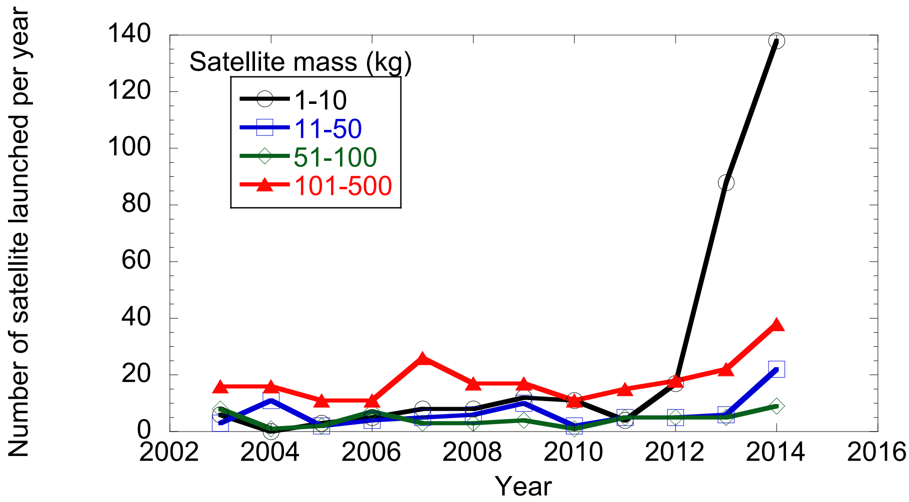

Figure 1: Explosive growth in small satellite launches since 2012[9]

Kyutech strives to provide space environment testing and design techniques to the community in order to substantially improve mission success rates of future satellite projects. In doing so Kyutech utilizes laboratory research on practical satellite usage and testing standardizations to simultaneously train students and engineers while impacting the community as a whole. For example, Kyutech is planning to organize SEIC student cohorts starting from October 2015 to design, build, launch and operate multiple 1U lean CubeSats as educational tools under Masters or Doctoral study.

This approach creates ideal opportunities for emerging countries and institutions that may lack resources necessary to conduct traditional satellite missions to cooperate on lean satellite projects. For effective capacity building it is crucial to sustain the progress being made in technical skills, management skills, and space

[9] Source: Kyushu Institute of Technology

engineering. Numerous new-generation space engineers are being produced in Japan and many other parts of the world. But, human resource development conditions in some countries are fragile. Proliferation of lean satellites is one attractive solution for new-generation space engineers to maintain contact, offer practical support, and generate funding while engaging in projects worldwide.

4.2 Global space utilization via lean satellites

Lean satellites are allowing new users worldwide to access and utilize space. Small or lean satellites employed in constellations offer the most significant advantage of small/lean satellites applications over traditional satellites. For example, an equatorial constellation of five or six lean satellites could provide continuous surface coverage and continuous satellite-to-ground access in Earth's equatorial latitudes. Such a constellation could be achieved on a single launch to a single orbital plane, drastically reducing launch cost.

Efforts are on-going at Kyutech and institutions throughout the world to accomplish the following with lean satellites:

- Mission/satellite architectures that serve global purpose
- Innovative methods to reduce development time
- Innovative methods to reduce cost

These endeavors will continually lower the barrier to space access, and allow new nations to utilize space for the benefit of humanity.

5 Discussion on capacity building intent and alternative approaches

Space access has never before been so attainable for new space actors. In the past five years alone, 19 countries have achieved their first satellite in orbit. By the end of this decade, that number will likely be over 30 [1]. The contribution by small and lean satellites is shown in Table 3. The first satellite achieved is increasingly of the small/ lean type. About ~50% of maiden satellites launched so far this decade have been domestically self-developed. In the 1990s and 2000s this rate was around 25% [1]. Capacity building effects are clearly present is this trend. It is worth considering the intent of capacity building, and advantages and disadvantages of various approaches.

Table 3: Maiden satellite type by decade

	1990s	2000s	2010s	Total
Small/lean:	2	3	8	13
Traditional:	14	10	11	35

5.1 Intent of space-related capacity building and human resource development

The intent of space-related capacity building and human resource development is self-sustainability. Self-sustainability requires not only prerequisite technical skills and a critical mass of suitable personnel, but also vision. Successful capacity building must impart perspective and long-term planning with respect to space activities, if previously lacking in the local cohort. To achieve the stated intent, models should consist of numerous aspects, including but not limited to a combination of the following:

1. Theoretical and hands-on training in necessary space-engineering technical skills and design
2. Project cycle experience including design, development, verification, launch, and operation
3. Project management experience resulting in competence to manage projects autonomously
4. Business model fundamentals and the ability to pitch space projects to funding sources
5. Understanding of minimum required infrastructure for different levels of space activity
6. Empowering individuals to initiate space projects from scratch

7. Imparting creativity to make programs less dependent upon government policy
8. Imparting "no excuses" mentality
9. Imparting vision and inspiration

Capacity building and human resource development must take place either within a given country or abroad. Typically, a combination of the two is most effective. There must be at least one domestic institution to foster projects and human resources. In most cases the initial training is obtained through contact with international entities.

5.2 Advantages and disadvantages of alternative approaches

The primary focus thus far as been on Kyutech's university-based capacity building model from the trainer perspective. From the trainee perspective, emerging countries must consider both the domestic fostering environment and the external training environment. The fostering environment typically falls into one of three categories, as does the training environment: agency-based, company-based, or university-based. We attempt to identify advantages and disadvantages of all three common approaches for both the fostering environment and the training environment from the trainee standpoint.

5.2.1 Agency-based

There are numerous examples of emerging countries using agencies to foster their space programs, such as the Bolivian Space Agency (ABE) in Bolivia and the National Space Research and Development Agency (NASRDA) in Nigeria. Established space agencies such as NASA, ESA, JAXA, etc. offer training. Advantages and disadvantages for the agency-based fostering and training environments, respectively, are shown in Fig. 2.

Fostering environment (agency)		Training environment (agency)	
Advantages	Disadvantages	Advantages	Disadvantages
Dedicated program that may include numerous projects in parallel	Proportionally higher administration and non-technical expenses	Instructing agency has performed many successful space missions	Difficult to obtain authorization to autonomously operate equipment
No inherent ceiling to program growth	Susceptible to political instability	Wide variety of mission types and training options to learn from	Predominantly short-term, intermittent training
Presumably funding exists	Bureaucratic	Access to established space experts	Limited project incubation

Figure 2: Agency-based advantages and disadvantages

5.2.2 Company-based

Space programs can be fostered at public companies, such as RENATELSAT in the Democratic Republic of the Congo, or at private companies, such as Sequoia Space in Colombia. Examples of companies providing training include the China Great Wall Industry Corporation (CGWIC) in China and Thales Alenia Space of France and Italy. Surrey Satellite Technology Ltd (SSTL), a spin-off company from the University of Surrey, self-reports having caused six space programs to “emerge.” Advantages and disadvantages for the company-based fostering and training environments, respectively, are shown in Fig. 3.

5.2.3 University-based

In some countries universities are fostering space programs. For example, Nanyang Technological Univesrity (NTU) and National University of Singapore (NUS) in Singapore, and the Costa Rica Institute of Technology (TEC) in Costa Rica. Universities offering degree-based space engineering training include Kyutech in Japan, University of Surrey in the U.K., Cape Peninsula University of Technology (CPUT) in South Africa, Beihang University in China, and others. Advantages and disadvantages for the university-based fostering and training environments, respectively, are shown in Fig. 4.

Fostering environment (company)		Training environment (company)	
Advantages	Disadvantages	Advantages	Disadvantages
Disruptive technologies lowering barrier to space access	Early-stage failure folds business	With sufficient funding can obtain highly customized training	Often need to purchase satellite to access training package
Venture cash flowing in	Profit based decisions may trump needs of country	Project incubation	Predominantly one-off training
Agile	Answer to investors	Short lead time	Limited flexibility and variety

Figure 3: Company-based advantages and disadvantages

Fostering environment (university)		Training environment (university)	
Advantages	Disadvantages	Advantages	Disadvantages
Less susceptible to abrupt loss of funding due to change in government policy or political instability (especially private universities)	Low ceiling (program likely will not extend beyond research and development satellites)	Lean satellite project cycle, including launch and operation, can be matched to degree timelines	Trainee (student) attrition to other fields or industries
Lean satellite project cycle, including launch and operation, can be matched to degree timelines	Reduced quality and mission value compared to professional projects	Learning from mistakes is encouraged	No immediate or short-term return
Ease of information sharing in academic environment	Increased likelihood of mission failure	Fully hands-on and autonomous	Limited facilities and infrastructure
Inexpensive labor		Wide international appeal and can more easily include non-engineers	Limited professional training
		Continuous pipeline	

Figure 4: University -based advantages and disadvantages

5.2.4 Other approaches

Other possible approaches include but are not limited to philanthropic endeavors, amateur radio clubs, crowd funding, open-source information sharing, and other activities carried out by space entities.

5.2.5 Combining approaches

Please note that approaches are not mutually exclusive of one another. In many cases the "best" approach may be to combine or hedge with multiple capacity building models simultaneously, such as in the case of the United Arab Emirates (UAE). The UAE has launched at least seven satellites (two to LEO and five to GEO) [19]. The two LEO satellites were launched by the Emirates Institution for Advanced Science and Technology (EIAST), three GEO satellites have been launched by Thuraya, and two GEO satellites have been launched by Yahsat. The first satellite, Thuraya 1, was developed by Boeing and launched in 2000 [8]. An approximately 45 member team from EIAST spent eight years (2006 to 2014) in South Korea under a capacity building project developing DubaiSat-1 and -2 with Satrec Initiative. In 2015 the UAE opened the Mohammed bin Rashid Space Centre to manage phases of UAE's probe exploration mission to Mars and to contribute to space science and satellite projects. In parallel, EIAST is coordinating CubeSat projects with domestic universities. Substantial funding and political support is necessary to simultaneously pursue multiple approaches.

5.3 Optimal capacity building approach

An optimal capacity building approach should achieve as many aspects as possible from 1 to 9 as given in Sec. 5.1 within a reasonable time period at attainable cost. Naturally, the optimal approach may vary drastically from one institution to the next. However, for emerging countries striving to achieve self-sustainable space programs with limited resources, as a first step we recommend a university-based fostering environment in conjunction with an external university-based training environment.

As shown in Table 3, pilot satellite projects are trending to small/lean. The entire project cycle from initial design to operation in orbit can be achieved within two years or less, well-matching typical Master degree timelines. Under this approach, the timeframe of capacity building can be synced with the natural academic cycle and pipelines can be established to feed the local workforce. The academic training program can be tailored to include real mission project management, business model fundamentals, and funding acquisition practice. Furthermore, start-up cost and labor cost to the fostering university is minimized, and academic funding is likely to be less dependent on government policy than direct space agency allocations. Under this approach the fostering university can build and launch a satellite with limited funds.

This first small/lean satellite is only a single milestone, albeit a decisive one, in strategic space/satellite program development. The long-term (~10 year) plan is governed by the end goals and needs of the country. For these objectives a steady supply of competent human resources is required. This model continuously provides said resources. The external university-based training program contributes directly to technical skills and indirectly or directly to leadership, systems engineering, and project management. Participants learn to initiate and autonomously manage projects that have strategic goals.

To ultimately convince the fostering government to pursue a dedicated space/satellite program, there must be at least one or two leaders who demonstrate satellite projects and push government officials. A university is a neutral, academic institution that can conduct first-generation satellite activities and form the core. The crucial point is that a satellite can be delivered to orbit with limited resources by individuals from the home country and the working culture will be established.

6 Conclusion

Kyutech's space-related capacity building project has expanded considerably since 2013 in response to a growing trend and worldwide demand for small/lean satellite technology and space engineers in emerging and non-space faring countries. Kyutech's model utilizes practical satellite projects and hands-on satellite testing to educate students and engineers from regions worldwide. Kyutech's Space Engineering International Course (SEIC) is based in English and designed to empower individuals to lead or start satellite projects in their home countries.

UNOOSA and the Japanese government provide substantial support for Kyutech's capacity building project. In addition to training PNST and self-funded students, Kyutech will continue to visit space-related institutions worldwide, seek capacity-building agreements, develop low-cost fast-delivery small/lean satellite testing, and provide assistance with launch opportunities. The authors advocate that emerging countries with nonexistent space programs and limited resources foster the first satellite project in a university-based environment with an external university-based training partner. Under this model the pilot satellite stands to increase the likelihood of both project success and program sustainability in the long-term.

Kyutech is working with noted space policy expert Dr. Danielle Wood of Johns Hopkins University to evaluate and critique SEIC and Kyutech's global space-related capacity building network. Primary objectives are to formally assess effectiveness and determine methods to heighten impact and contribution to the global space community.

Acknowledgments

The authors are deeply thankful to all partner institutions and hosts worldwide who contributed or are contributing to this activity. We also acknowledge stimulating, in-depth discussion with Dr. Danielle Wood that significantly enhanced our work on many of the topics herein.

References

[1] John Polansky and Mengu Cho. Classification of countries worldwide according to satellite activity level. TRANSACTIONS OF THE JAPAN SOCIETY FOR AERONAUTICAL AND SPACE SCIENCES, AEROSPACE TECHNOLOGY JAPAN, submitted for review (ists30): xx, 2015.

[2] MarketsandMarkets. Nanosatellite and Microsatellite Market, Worldwide Market Forecast (2014 2019). MarketsandMarkets, 2014.

[3] Mengu Cho, Hirokazu Masui, Shunsuke Iwai, Tatsuya Yoke, and Kazuhiro Toyoda. Three hundred fifty volt photovoltaic power generation in low earth orbit. Journal of Spacecraft and Rockets, 51(1): 379–381, 2013.

[4] Mengu Cho, Hirokazu Masui, and Kyutech Satellite. Nano-satellite development project and space engineering education at kyushu institute of technology. In Recent Advances in Space Technologies (RAST), 2013 6th International Conference on, pages 1059–1063. IEEE, 2013.

[5] Danielle Wood and Annalisa Weigel. The use of satellite-based technology to meet needs in developing countries. In Proceedings of the 59th International Astronautical Congress. Glasgow, Scotland, 2008.

[6] Danielle Wood and Annalisa Weigel. Building technological capability within satellite programs in developing countries. Acta Astronautica, 69(11): 1110–1122, 2011.

[7] Danielle R Wood. Analysis of technology transfer within satellite programs in developing countries using systems architecture. In American Institute of Aeronautics and Astronautics Meeting Papers, 2013.

[8] Robert C Harding. Space policy in developing countries: the search for security and development on the final frontier. Routledge, 2012.

[9] Mitsubishi Electric Corporation. Mitsubishi electric to deliver two communication satellites to Turkey, 2011. [Online; accessed 9-May-2015; http://www.mitsubishielectric.com/news/2011/0308.html].

[10] Wikipedia. Turksat 4a — wikipedia, the free encyclopedia, 2015. [Online; accessed 9-May-2015; http://en.wikipedia.org/w/index.php?title=T%C3%BCrksat 4A&oldid=648902859].

[11] Paul Kallender-Umezu. Japan, vietnam sign deal for two radar imaging satellites, 2011. [Online; accessed 9-May-2015; http://spacenews.com/japan-vietnam-sign-deal-two-radar-imaging-satellites/].

[12] United Nations Office for Outer Space Affairs. Basic space technology initiative (bsti), 2015. [Online; accessed 9-May-2015; http://www.unoosa.org/oosa/en/SAP/bsti/index.html].

[13] Eric Hand. Feature: Cubesats are swarming- and transforming space science, 2015. [Online; accessed 29-April-2015;http://news.sciencemag.org/space/2015/04/feature-cubesats-are-swarming-and-transforming-space-science].

[14] Mengu Cho. Reliability growth of small-scale satellites through testing: Monte carlo simulation. In 5th Nanosatellite Symposium, 2013.

[15] University Space Engineering Consortium. Introduction to the mission idea contest: Resource providers, 2015. [Online; accessed 10-May-2015; http://www.spacemic.net/index.html].

[16] M Cho and W Balogh. Capacity building in basic space technology development through on-the-job training in nano-satellite design, building and testing. In 61st International Astronautical Congress, 2010.

[17] M Cho, J Polansky, and W Balogh. Engineering education through on-the-job training in nanosatellite for capacity building in basic space technology development. In 64th International Astronautical Congress, 2013.

[18] J Polansky, M Cho, and W Balogh. Nano-satellite project-based learning for capacity building in basic space technology development. In 65th International Astronautical Congress, 2014.

[19] Ting Wang. A collection of satellite database, 2015. [Online; accessed 1-May-2015; http://satellitedebris.net/].